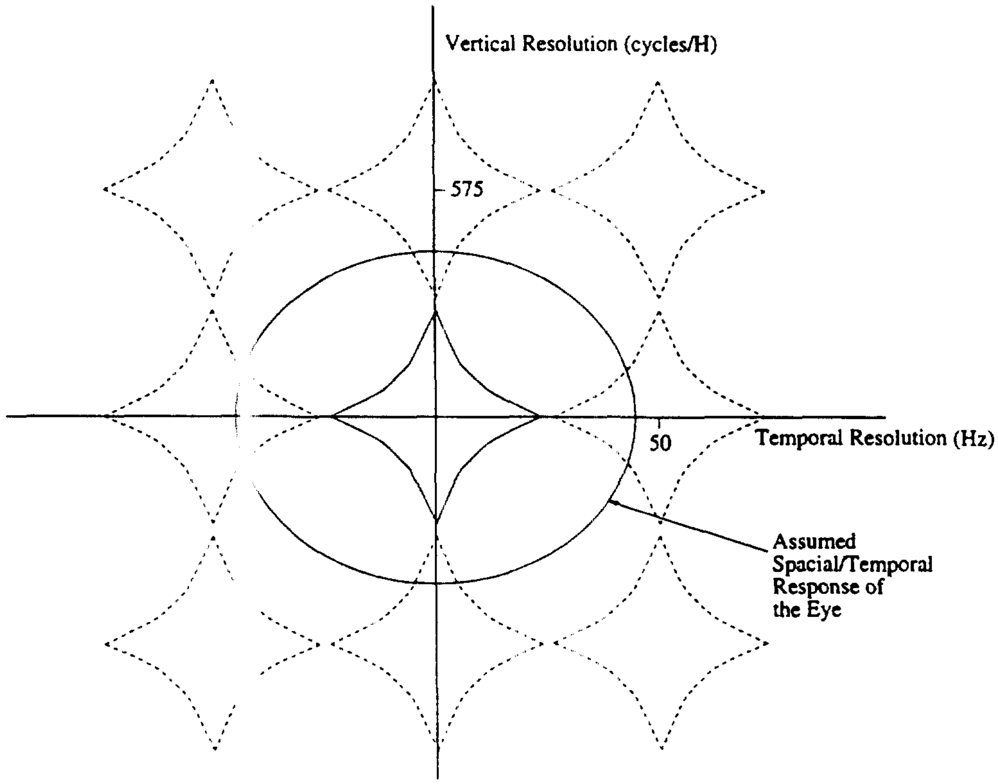


Figure 7: Repetition of the spectra for progressive scan (50Hz/575 lines)

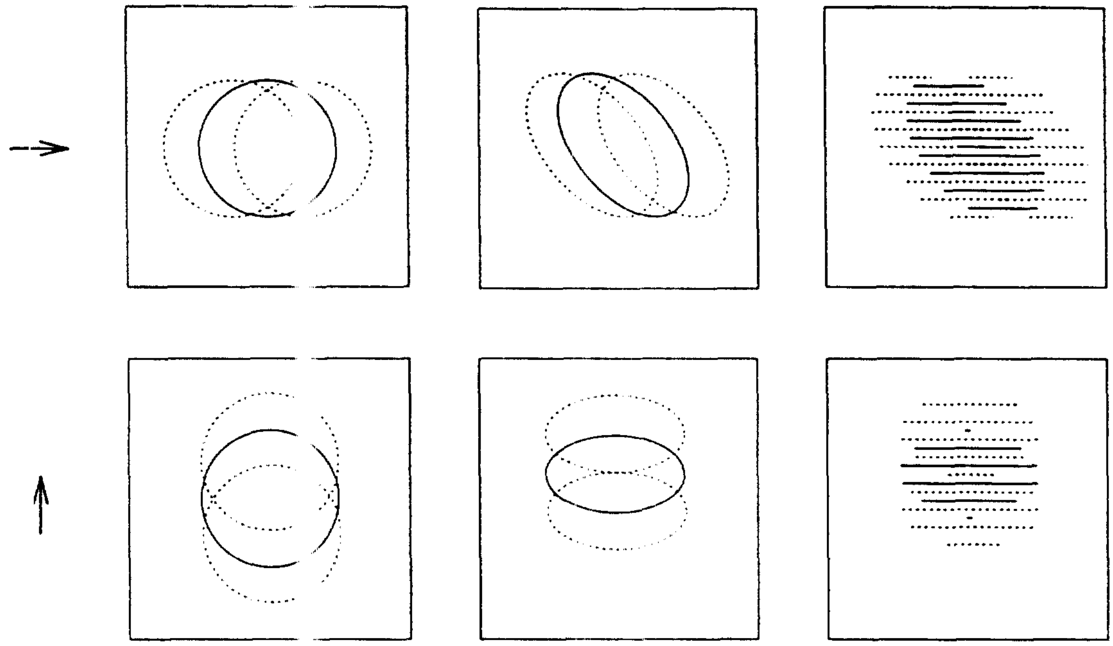
if effective SNR in camera operation is to be considered (after gamma and aperture correction), it leads to Table 1, performed on HDTV 1125 lines cameras [8].

Image Device	Tube		CCD	
Scanning system	Interlace	Progressive	Interlace	Progressive
Signal bandwidth (MHz)	30	60	30	60
Nominal SNR (dB)	47	38	around 50	41-47
Effective SNR in camera operation (dB)	34-38	25-29	37-40	29-37

Table 1: Effective SNR estimate of 1125 lines HDTV camera

It can be observed how the technological gap between interlaced and progressive is considerably reduced passing from tube to CCD. Moreover, although in a first period mostly interlaced cameras have been developed, an interesting recent realization [9] shows that the specific design of a CCD video camera for progressive scanning allows to increase significantly its performances, with a cost comparable to that of interlaced. In particular this realization is a 525 lines 1:1 16:9 camera that employs a new image-capture system called *Multiple-Frame-Interline-Transfer* (M-FIT). The M-FIT CCD is a different design for the storage-cell and for the signal transfer mechanism between the photo diode and the storage-area, which leads to a dynamic range twice as large as that of a conventional device, owing to the use of the M-FIT CCD for progressive scanning with similar performances as conventional CCD for interlaced one.

Depending on the camera technology which is used, i.e. tube or CCD, the motion rendition of moving objects may also differ [11]. Figure 8 shows the motion rendition of a disk moving at constant velocity (horizontal and vertical motions) across the field of view, as shot by the different camera types.



(a) Progressive frame-transfer CCD

(b) Progressive line-transfer CCD or progressive tube-type camera

(c) Interlaced tube-type camera

Figure 8: Motion rendition of a moving disk

As illustrated, using a progressive frame-transfer CCD camera allows to shot frames like a photograph. This improves the picture display, especially when there is a need for displaying slow motion or still picture. Tube scanning (interlaced as well as progressive) or line-transfer CCDs suffer from distorsions due to the movement of the object during the capture of the image.

Apart from video-cameras an important source of motion picture material for future television is constituted by films. Film is a medium that will never suffer of any backward compatibility problem because its recording quality is the highest possible, it can be considered as an extremely high-band RGB. The importance of the archives maintained by the cinematographer companies is considerable (Hollywood studios and production community dispose of the largest library of motion pictures in the world), so it is not negligible to study how to optimally convert this source material into digital data. If we do not consider the debate on optimal resolution and RGB-to-YUV conversion, it is generally agreed that a 25Hz (24Hz) progressive scanning is the base condition. Compatibility with existing interlaced TV sets is therefore guaranteed by use of frame-repetition (as in the MPEG2 case). This repetition does not produce evident motion jerking effects, due to a series of technical tricks used when filming with a cine-camera, that otherwise could occur if a 25Hz video-sequence is converted to 50Hz by simple frame or field repetition without considering temporal aspects (like the exposure time for example).

Thus, from the source point of view, progressive scanning is the best candidate when film materials are used and the latest technological progress allow video progressive CCD cameras to be used with the same quality as interlaced ones.

5 Signal Processing Aspects

The second item inside the Recommendation on scanning formats [12] states that a progressive scanning makes most signal processing operations much easier than interlaced scanning, e.g. vertical filtering, interpolation and decimation, slow motion, still picture display, multi-resolution analysis, hierarchical coding and pre-display processing. The most common comment to this affirmation is that this operations are apparently easier, but since all the systems must work with a doubled clock frequency and with higher memory usage, the real complexity is greater and not lower for progressive.

In this section the most important signal processing operations commonly applied to the video signal are examined, focusing the attention on scanning format requirements and evaluating their complexity impact in a proper scenario where it is above all distinguished between services to be realised at the broadcasting side (slow motion, chroma-keying), at the receiver side (still picture, interoperability) or at both sides with different complexity and quality (format aspect and frame rate conversions). The first couple of signal processing operations which merits to be considered regards logically the mutual scan conversion in order to evaluate their complexity.

5.1 Deinterlacing / Reinterlacing

Compatibility between interlaced and progressive can be achieved only if the conversion algorithms can guarantee a sufficient picture quality at a moderate cost. It is generally known that deinterlacing is more complex than reinterlacing because new information not present in the input data must be created.

The results of Race TRANSIT works (recently come to conclusion), can be used to state these debates [13]. They prove that a satisfactory progressive to interlaced conversion is achievable through a vertical low-pass filter, characterized by a frequency response accurately designed and well-reproducing the one of a real interlaced camera (Kell factor), followed by a vertical subsampling with different phase for the two fields. This study on the filter shape has produced various good filters well tested in literature, such as the 11-tap known as HHI filter.

On the contrary, in order to reach a comparable quality in the interlaced to progressive conversion it is clear that a sophisticated technique, based on a combination of motion analysis and spatial interpolation, is needed. Moreover, the motion estimation algorithm is usually specifically designed to this aim, since classical block-matching implemented for coding purposes does not fit the specific constraints. Subjective assessments have been performed based on test-sequences and the evaluation of the scores shows a significant gap between the motion compensated deinterlacing algorithms and the other solutions (low-cost linear interpolations). The utilization of such complex techniques at the receiver side, i.e. after the decoding of the interlaced bit streams, does not seem realistic today and it would be surely of interest to pursue studies on effective low-cost solutions, possibly making use of standard MPEG2 motion information.

The HAMLET Extension on Scanning Formats intends to investigate the possible advantages of using a progressive format as an intermediate format for the coding of interlaced images. Unlike TRANSIT development, HAMLET deinterlacer is meant to be placed upstream the coder. In order to get the best coding efficiency, a particular attention must be paid to the quality of the reconstruction of the progressive sequence from the interlaced input. The deinterlaced sequence has to represent the "analog" scene hidden behind the interlaced input as well as possible. In other words, the fields added to the interlaced sequence for converting into progressive must be spatially and temporally coherent with the already existing fields. In particular, the calculation of the motion vectors must be finely tuned and a method allowing a perfect reconstruction has to be found. The analysis inside HAMLET will be based on the *general sampling theory* which was proposed recently to handle interlaced images and proved to be successful [14, 15].

5.2 Filtering

Vertical filtering is intrinsically more effective for signal sampled on a progressive grid, both in terms of complexity and final results.

If the interlaced filtering is performed *intraframe*, although two frames have to be processed for progressive at the time of only one for interlaced, adjacent vertical pels are available with a delay of 20 ms, and all the process could be executed in real-time at the same speed as progressive. Moreover, filtering two fields merged produces ghost-effects and motion judder in presence of motion.

If the interlaced filtering is *intrafield* the process could be sped-up, but two more sophisticated filters have to be designed (phase linear/not linear, phase shifting) and results are degraded in presence of critical patterns (near horizontal moving lines) producing annoying artefacts. Note that this second solution is currently employed with effectiveness inside the 4:2:2 $\rightarrow$ 4:2:0 MPEG2 pre-processing but in this case the filtering is applied on the much less critical chrominance components. The same conversion for a progressive MPEG2 encoder, usually requires a trivial 3-tap filter (so faster to be implemented than the two classic 7-tap FIR of interlaced) and offers better performances of almost 1 dB.

5.3 Multi-resolution analysis - HDTV/TV scalability

Multi-resolution processing of video signals could be historically divided in two great domains: frequency scalable and spatial scalable techniques. In the former the downward conversion HDTV-TV is performed in the frequency domain (subband, DCT) through a proper selection of a sub-pattern of spectral coefficients, while the latter provides conversion by FIR filtering (vertical or vertical/temporal). Within MPEG2 scalable profiles, the spatial scalability is the only scalability feature accepted by the standard where picture spatial resolution is involved. Frequency scalability, although deeply considered during the preparatory working years of the expert group, has been discarded at the end, mainly because interlaced performs poorly in terms of separation of the vertical frequencies. The encoded MPEG2 signal can produce a decoded lower layer with high quality (apart from drift problems) from the simplest data partitioning operation (e.g. the selection of the lowest transmitted coefficients), only effective with progressive scanning. Moreover, an intermediate progressive step is often considered in interlaced-to-interlaced conversion, as actually recommended inside the specifications of a spatial scalable MPEG2 decoder when processing the lower layer to build the spatial prediction for the higher layer [16]. Other studies [17] pointed out the clear theoretical advantages of progressive sampling lattice in scalable applications and suggest that the transmission of the only progressive signal could guarantee a good compatibility with both HDTV and TV receiving systems.

5.4 Slow Motion

Slow motion can be regarded as a conversion to a higher frame rate (see the subsection 5.7). The increased frame rate is displayed at the same original frame rate, thus slowing down the action. Conventionally, slow motion replay has been achieved by simple field repetition, process that gives rise to undesirable jerky motion effects. To overcome these problems high-quality slow motion algorithms recently projected [18, 19] are all based on high-quality deinterlacer, specifically projected or adapted to this purpose. Typically the whole process is a cascade of such deinterlacer followed by a temporal interpolation, where the number of intermediate interpolated pictures depends on the desired target frame-rate. This application is considered as a broadcast service because in a short scenario it will take the place of dedicated cameras currently used especially for sport applications. In the future, it may become available as an add-on TV domestic feature.

5.5 Chroma-keying

Digital chroma-keying is intended to replace the historical analog process based on the use of the blue component to separate elements from a scene. Basically good performances in isolating objects from an image to overlap it on another are achievable only through good region and contour detection, surely easier in progressive scanned picture than in blurred (since field-merged) interlaced picture. Within the researches currently under development always progressive reference material is considered.

5.6 Aspect Ratio Conversion

Aspect ratio conversion can be used both at the transmitter and receiver sides. Typically, it concerns the conversion between 4/3 and 16/9 formats. Probably digital television will start in 16/9, so the problem of compatibility with 4/3 material is real. The re-sampling is essentially a filtering problem (pure horizontal, pure vertical or mixed), where above considerations on vertical filter and scanning format are valid.

5.7 Frame Rate Conversion

This conversion can be used at both transmitter and receiver sides. It primarily concerns conversions between :

1. 50Hz/59.94Hz/60Hz : compatibility between European/Japanese and American standards.
2. 50Hz/100Hz : a means to improve video domestic quality still using an interlaced TV screen, so saving compatibility; due to this advantage it has already found a place in the market. Some upgrades to the pure intra algorithms, making use of motion estimation are already available. This new solution [20] is provided by the cascade of a deinterlacer, a temporal interpolator and a reinterlacer, in order to obtain an interlaced 100Hz sequence where only every fourth picture is an original. The complexity of the algorithm presently fits better with studio or broadcasting application.
3. 50Hz/72Hz : workstations and PC monitors often work at the frequency of 72Hz because these displays are viewed from a much closer distance than TV set and so a higher fame rate is considered necessary to eliminate any visible flicker. In the framework of windows containing video, this conversion problem copes with interoperability between digital television and multimedia.

5.8 Still Picture

If the picture to be displayed in still-mode is progressive, this process is automatic and reduces to an editing problem. If the incoming signal is interlaced an interpolation is logically needed. The quality of the deinterlacing algorithm is in this case more critical because artefacts are actually clearer than what can appear in motion. Even more if the purpose is to grab the image and record it as already possible nowadays with some multimedia software.

5.9 Interoperability with Multimedia

The mere fact that video and audio data is in a digital form is itself a form of interoperability. This is already a significant improved step compared to analog. Compliance with international standardization rules is the second condition of bit stream interoperability. Another more complex issue is whether the transport that is suitable for consumer application is also suitable for computer workstation applications. The Planning Sub-committee Working Party-4 of the FCC Advisory Committee for Advanced Television Services [21] has identified several key-requirements for interoperability in the US ATV system. About display issues, the choice of a progressive scanning was considered as relevant (PS/WP4 Rec.3).

The objective usually called "HDTV on computer workstations" or "multimedia TV terminals" is achievable through video processor modules able to resize the input signal, convert it into a window, locate it and overlapped it with computer graphics or other video windows. In the resize process a deinterlacer step is always present to maintain good quality.

6 Coding Aspects and Future Work inside the HAMLET Scanning Extension (WP2)

When working with digital video, digital image compression has to be performed in order to transmit the data with a reasonable bit rate. Since compression is performed, the picture quality is no longer directly linked to the resolution of the picture (in number of pels) but depends on how compression is achieved (however, the picture resolution gives an upper limit to obtainable picture quality). Considering a compression like MPEG2, picture quality may vary according to the output bit rate, the quality of the motion estimation and the scanning format used within the coder.

Coding moving interlaced pictures as merged fields exhibits "combing" due to the temporal offset between scanning the first and the second field. This effect generates a range of high frequency DCT coefficients when frame blocks are coded and increases the number of bits that are required to transmit the block. To get round the combing problem, MPEG-2 can use field DCT modes which transform the two fields separately, based on an inter field motion compensation. However, the increased spatial distance between field lines make field DCT mode less efficient than frame DCT modes when combing is absent. Further, the increased temporal spacing between fields of same parity degrades the quality of the coders motion-compensated prediction and augments the number of bits required to send the predictor error signal [22, 23]. Also, the existence of field aliasing make the research of the true motion vectors between fields more difficult [24]. The absence of combing in progressive pictures increases the correlation between pixels within a block, which concentrates the blocks energy into fewer DCT coefficients when transformed, and consequently lowers the transmission bit rate. The disadvantage of progressive formats compared to interlaced is the increased pel rate. The question is whether the improvements in bit rate reduction efficiency due to progressive coding can overcome the increased pel rate.

From the point of view of a theoretical analysis of the source coding efficiency of interlaced and progressive format, the first step is the design of a reliable model of both the video signal and the coding process. This aim is achievable only under some assumptions and constraints. Such models can be found in the literature as in [25] where they are built up and studied, and in [26] for a compared analysis. Briefly, the former is a study intending to get more insight in the nature (and the intrinsic limits) of interlaced signal, developed mainly in the Fourier domain and based on the following assumptions: spatially band limited scene characterized by global motion and directly sampled on a quincunx vertical/temporal grid; the latter work, assuming an ideal Nyquist progressive sampling (the interlaced sequence derives by subsampling), adopts a specific model for the source sequence, a stationary Gauss-Process with isotropic PSD. The first common stage is the Intra analysis. In [25] the intrafield processing gives evidence to the two alias terms in each field's spectrum, with opposite sign, which disappear in intraframe case when no-motion between the two fields occurs. In [26] the intrafield interlaced coding is compared with intraframe progressive coding by means of Rate/Distortion curves obtained through the model, and showing better performances for interlaced. Moving to interframe motion compensated processing (hybrid coding), both the models allow to enhance the intrinsic constraints of interlaced representation for both the motion estimation and the motion compensated interpolation. In [25] the inherent advantages of the interfield same parity motion compensation, rather than opposite parity are also proved.

The MPEG-2 coding reference model accepts both interlaced and progressive pictures, but only the 25Hz/625 lines 1:1 format conforms to MP@ML, while decoding the 50Hz/625 lines 1:1 format presently requires the much more expensive H1440L designed for the HDTV. This is a real gap for progressive in the framework of an evaluation made upon a realistic scenario, and to this aim in [12] is suggested to define an intermediate MPEG level compatible with the 50Hz/625 lines progressive format. However, as done for all this paper, for the future work, we will consider a progressive format with a conventional double number of pel, i.e. a double amount of information. And about coding, the aim of the simulations is to test the capacity to use efficiently the increased spatial and temporal correlation present inside statistic data available after a progressive sampling. It is to be considered however that, since the MPEG2 was mainly developed for interlaced and used with interlaced material as reference, it contains some mechanisms like the frame/field choice for the prediction and for the DCT transform which allow to subdue its intrinsic constraints. The MPEG2 Draft Recommendation leaves some degrees of freedom in the project of the encoder, so a wide range of them has been developed and tested during the last two years, starting from the TM4 reference model. Inside HAMLET/WP2 and in collaboration with the parallel research on the hardware carried on inside the WP5, a software codec has been developed by HAMLET partners and it is presently under modifications and optimizations to best cope with progressive. In fact many algorithmic simplifications are possible for an MPEG2 encoded designed on purpose for progressive signal: no need to choose between frame/field in picture type, in macroblock prediction and in block DCT transform, but also in the hierarchical motion estimator.

An important matter that will be explored at the final stage of simulation within WP2 concerns the visibility of coding artefacts produced by interlaced and progressive codecs. In other words, whether the effects of the rougher quantization is more annoying on progressive pictures than the amplification of flicker artefacts on interlaced ones or not.

Tests already have shown [22] that the coding of interlaced or progressive sequences is nearly equivalent when comparing the SNRs of the decoded sequences. Although a progressive format contains twice as many pixels as interlaced, it seems that the amount of information is not twice as large but may be seen twice as redundant. A good coding method eliminates this redundancy. It also has been found that coding progressive sequences may improve the subjective quality of the decoded sequence, even if the latter is displayed in a interlaced format [27]. Even if a interlaced scheme is chosen for the future digital television, an intermediate progressive format (inside the codec) may thus be useful in order to provide a better quality of the displayed sequence (interlaced or progressive) but also simplify further signal processing [15, 22, 28, 29].

About the doubled clock-frequency (sampling rate passes from 27 MHz of CCIR601 resolution to the 54 MHz of the corresponding progressive) basically two different approaches could be envisaged for a possible progressive encoder and decoder chips, taking into account present solutions adopted for HDTV interlaced encoder and decoder on advanced project inside HAMLET. The HAMLET H1440 encoder demonstrator [30] overcomes problems related to the high data-rate (4 times CCIR601, so 108 MHz) through a sophisticated parallel architecture based on 4 coding processors working each on a vertical stripe of the picture at standard TV data-rate; this solution makes possible the use of already experimented ASIC chips designed for SDTV encoding. The adoption of the same strategy could be envisaged for a possible progressive encoder (picture divided into 2 stripes instead of 4), and the additional complexity compared to an interlaced TV encoder is quite little. The H1440 decoder [31] on the contrary, since at the decoder side less computational power and memory size are needed, has been projected with an ad-hoc VLSI structure that processes the whole picture data, an 110 MHz input data stream. Although a parallel architecture is internally used when possible (IDCT, dequantization, low layer and high layer) there are chipsets running at 54 and even 67,5 MHz, so at the limit of VLSI technology. Taking into account these experimented data, a progressive TV decoder could be seen as a downscaling of the complexity problems here already solved.

7 Display Aspects

Television is the most difficult application of any display technology, requiring the ability to provide grey scales, full colour, rapid response speed (below 20 ms), high contrast (over 50:1) and brightness (at least 200 cd/m^2) with good uniformity (at least 5%), all at a relatively low cost. Up to now only CRT technology seemed to match these needed characteristics, but as in camera technology there is a fast growing of researches and developments in this area. New promising systems, which have already conquered lead positions in parallel applications (like LCD in portable computer displays and rear video projectors), now challenge CRT even as TV display. The most promising system configurations currently in advanced study are *Active Matrix LCTV*, *Digital Micromirror Device* and *Plasma Display Panel*, which present interesting behaviors for interlaced and progressive scanning formats.

Active matrix LCD is by now a mature technology [32]. The latest tests and comparisons show a picture quality near to CRT, with a considerable reduction in weight and dimensions. They work by incorporating in every picture element an active electronic device, usually a thin film transistor (TFT). However, even if the TFT is the most critical component of the system, picture quality depends also on the properties of the liquid crystal, on the colour filters and upon the way the display is driven. In fact, although the basic performances of these displays can often match that of a good CRT, when experimenting them with present TV transmission systems (PAL, SECAM, NTSC) some problems arise because these systems were specifically designed around CRT. Apart from the gamma pre-correction which is applied at source and specifically designed on the brightness-voltage curve of CRT, thus producing distortion on LCD, the more important problem is the use of interlaced scan. Pixels belonging to lines of one parity are addressed in every other field, i.e. each 40 ms for PAL. Due to the temporal response of an LCD element, more similar to a flat response rather than to the typical decreasing characteristic of the beam-target interaction of CRT, these pels can often be visible when the other field is presented after 20 ms. This phenomenon has no consequence for stationary regions but gives unpleasant smearing effects on the edges of moving objects. That is why usually an internal proscan conversion is performed (also in rear-projectors, see [33]), in order to drive the lines of each frame sequentially. The fact that the charging-time for the pel capacitance driven by the TFT must be reduced ($tc < 32 \mu s$) is no problematic with current technology.

Very promising but relatively new, so still in a prototype stage, is the technology named Digital Micromirror Device (DMD), a spatial light modulator. The DMD is a new kind of semiconductor technology [34] that combines electronic, mechanical and optical technology, in order to create an all digital display by the use of micro-mirrors reflecting light, each of them being associated with a picture element. Its peculiar characteristics are the minimal dimension of each image element, which allows high integrability in large scale (structures of 2048x1152 pels have been realised for HDTV purpose), and a good fastness in response to digital driving signals (usually bit-plane data PWM modulated). DMD projectors are two or three times more efficient than LCD technology when compared for brightness (increased optical efficiency of the mirrors compared to liquid-crystal valves). Unlike a conventional CRT which works in interlaced (the glow of the phosphor in the CRT persists long enough for the interlaced technique to work), the DMD has no persistence and must display the entire picture every 1/50 of a second. This makes the DMD well suited for future progressive displays. Inside the architecture already projected to support a DMD for the video available today, a proscan converter is always present.

Progressive scanning for Plasma Display Panel (PDP) is strongly desirable, because AC PDPs have inherent memory which requires, in interlaced operation, to switch-off the lines of the opposite field. It leads to line structure and 50Hz flicker. Moreover, PDP is an alternative to the LCD because of its very wide viewing angle, very large display size (1.5 meter diagonal with 2048x2048) and 24 bit color scale, and because AC plasma displays have a very long lifetime (40 years) [35].

As in the case of the examples found in literature for LCD, the algorithms employed for this interlace-to-progressive conversion are usually very simple (field repetitions, spatial interpolations). Global performances should surely benefit of an high-quality deinterlacing block placed upward in the video chain, and even more with progressive input pictures.

8 Scenarios for the Adoption of a Progressive Television Scheme

This section analyses three scenarios that might be used for the implementation of the future digital television and discuss their impact on the decision of adopting a progressive television format or not. These scenarios show that this decision basically depends on the choice of the broadcasting format. Two of these scenarios also show the possibility for both interlaced and progressive technologies to coexist, ensuring backward compatibility with old (interlaced) material during a transient period.

8.1 Scenario 1 : Interlaced Broadcasting Format

For this first scenario, we assume the adoption of an interlaced broadcasting format for all television programmes (see figure 9). It represents the worst situation for gradually switching to a progressive format. Indeed, in such a context, both studios and end-consumers have no advantage to move towards a progressive scheme :

- Since television studios have to deliver their programmes to broadcasters in an interlaced format it makes no sense to adopt a progressive format for whole studio chain: the improved quality of the progressive format will inevitably be spoiled at the reinterlace. However, a progressive format may be used for improving the quality of some local applications (signal processing, digital chroma-keying, etc.). This progressive format will be generated through the use of a deinterlacer, probably located inside the application box itself. Nevertheless, adopting a interlaced broadcasting format will force progressive to come down to a marginal format.

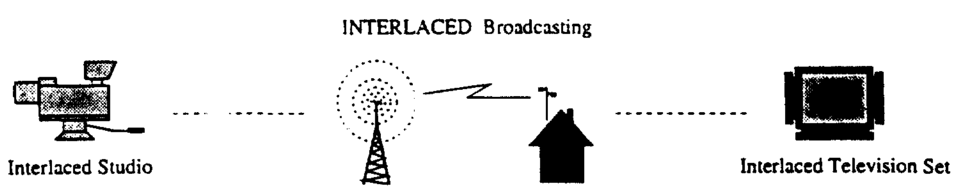


Figure 9: First scenario : Adopting an Interlaced broadcasting format

- It also makes no sense for the consumer to purchase a progressive display. Even if the use of a progressive television set may improve the visual quality of the displayed images, economical considerations will force the marked to offer receivers based on low-cost deinterlacers only. The slight quality improvement that will result will not balance the increased price and complexity of the progressive sets. Also, requiring about the same complexity, 100Hz-interlaced displays offer a much better improvement compared to the 50Hz-progressive displays, when both have to deal with a 50Hz-interlaced input.

8.2 Scenario 2 : Progressive Broadcasting Format

As second scenario, we will now assume the adoption of a progressive format for the broadcasting (figure 10). This choice give rise to new considerations :

- Current scenario allows *full progressive transmission*, from the very beginning of the process (image capture) to its far end (end-consumer receiving set). Compared to the first scenario, this scheme is able to improve visual quality (improved vertical definition and absence of the interlaced artefacts) at every stage of the process.
- *Compatibility with interlaced studio.* As intermediate step towards a full progressive scheme, "old" interlaced studio may keep their material and broadcast programmes by preliminary using a deinterlacer. Besides removing the interlaced artefacts (but not restoring the vertical definition loss inherent to the interlaced format as mentioned previously for the Kell factor) the deinterlacer is also supposed to improve the digital coding of interlaced sources. This last point will be studied in the next WP2/Scanning Formats deliverables.

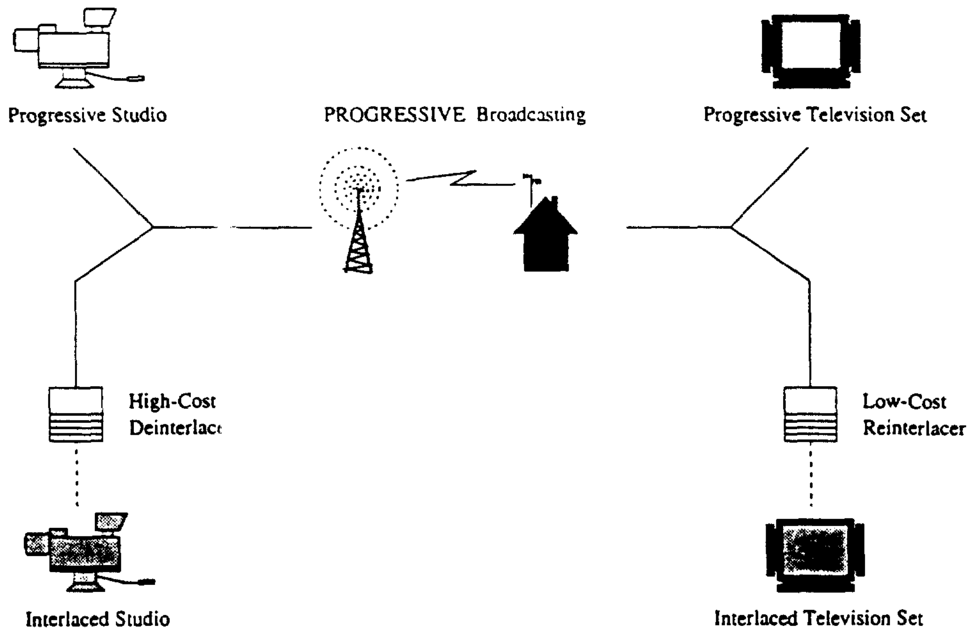


Figure 10: Second scenario : Adopting an progressive broadcasting format

- *Compatibility with interlaced receiving sets.* In order to receive progressive programmes, owners of interlaced displays will have to purchase a progressive to interlace converter. This format conversion is very easy to achieve and may be implemented as a low-cost settle box. Since progressive digital broadcast is expected to improve the coding efficiency, owners of interlaced displays will enjoy a better image quality compared to the first scenario, even if all interlaced defects will be generated at their display. Moreover, since the adoption of a progressive format goes hand in hand with the advent of the digital television, owners of an old analogue interlaced display will inevitably have to purchase a digital decoder. It's is foreseeable that this decoder will also offer the required deinterlacer at its output. So, besides the digital decoder, no additional format converter will be needed.

- Since the adoption of a progressive format give rise to higher image quality at every stage of the television chain, *the crossing between the interlaced and the progressive worlds will come naturally.*
- In the first scenario, we noticed that even if the consumers decide to adopt progressive displays, they would not be satisfied with since economic considerations will force the end user market to offer low-cost (implying low-quality) deinterlacers only. In the current scenario, the potential deinterlacer is located at the studio side and gives the opportunity to work with complex *high-quality format conversions.*

8.3 Scenario 3 : Free Broadcasting Format

As last scenario, we will now study the broadcasting of both interlaced and progressive formats, depending on the signal found at the studio output (see figure 11). This scheme results from the combination between the two previous scenarios. All considerations emitted for the second scenario remain valid. Since digital television is able to encode both interlaced and progressive formats using the same syntax (see the MPEG2 syntax), it makes possible the two formats to coexist and be broadcasted together.

- Interlaced studios are not required to use a deinterlacer at their output anymore. Interlaced programmes may then be received by the old television sets without format conversion, or by progressive displays through the use of a deinterlacer. Furthermore, the owners of a progressive display may take advantage of the increased horizontal scanning velocity of their television set, and switch to a 100Hz flicker-free interlaced mode, since the poor quality of the low-cost deinterlacing.
- In order to display progressive programmes, interlaced television sets will have to be coupled together with a reinterlacing settle box. Another (costly) solution would be the broadcasting of both interlaced and progressive versions of the same programme at the same time. However, it does not make sense since the adoption of a progressive format will probably coincide with the arrival of digital television. Consumers will have to change their "analogue" television sets or at least purchase a digital decoder. As we already mentioned, nothing prevents this decoder to include the required progressive to interlaced converter. No format duplex is thus needed for the broadcasting anymore.

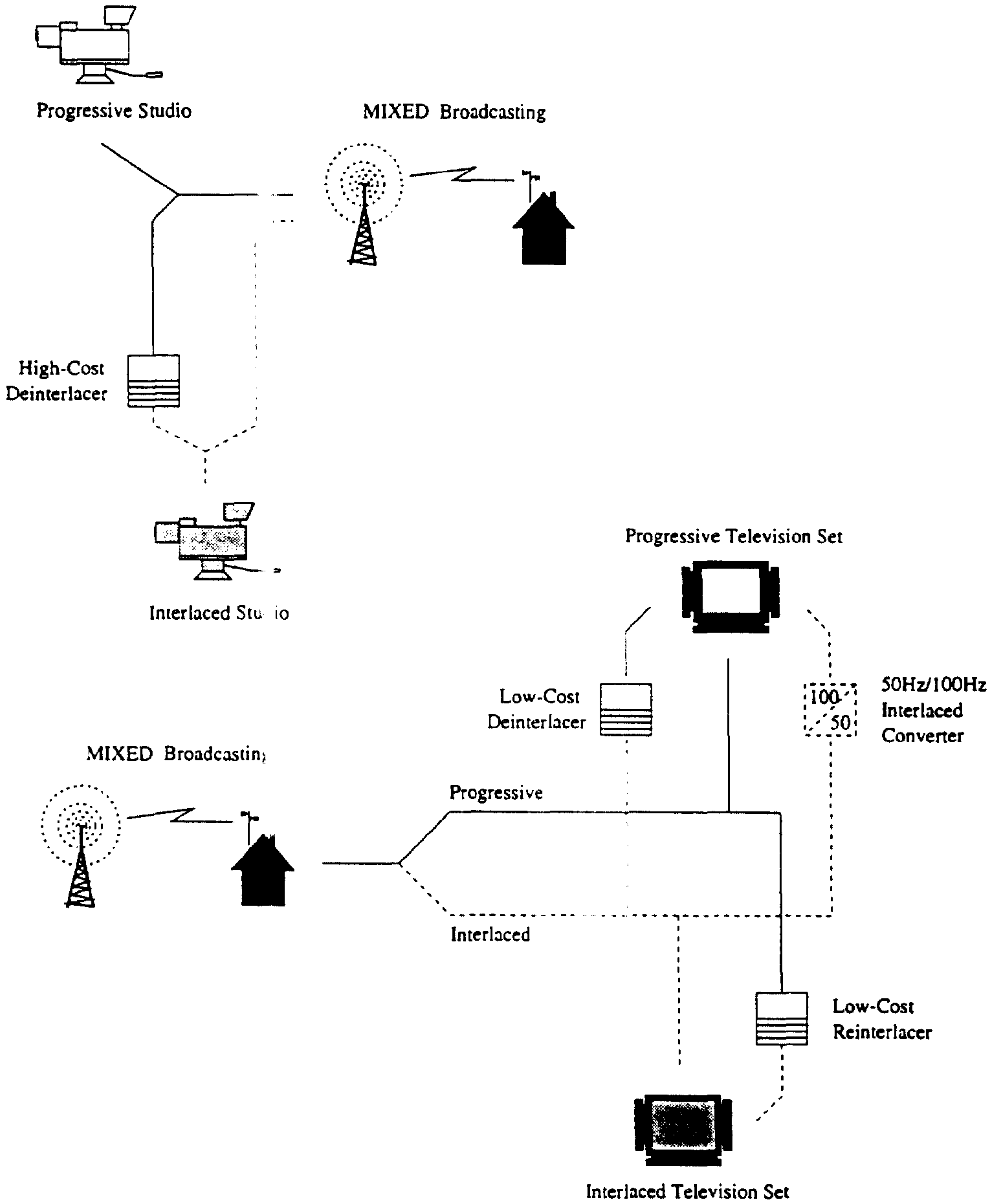


Figure 11: Th rd scenario : Adopting an free broadcasting format

8.4 About the Adoption of a 50Hz-progressive Format

The *Digital Video Broadcast* group (DVB) defined a set of standards that will be used to implement digital television transmission in Europe. The DVB standards describe digital television transmission over cable, satellite and terrestrial. All three standards are based on a MPEG2 main profile/main level coding (MP@ML). The differences are on the modulation techniques.

In the existing MPEG2 hierarchy, a 50Hz-progressive scanning format implies the use of the expensive MPEG2 high-1440 level which was designed to work with pixel rate up to four times higher than the main level. The 50Hz-progressive transmission lies in between these two levels and would ideally need the definition of an intermediate level at main profile. Such proposition was forwarded to the DVB and the MPEG Implementation Guidelines group in January 1995.

The 25Hz-progressive format can be reached with the main level. However, such format - probably ideal for 24 (25) Hz movies - may not be appropriate to cope with 50Hz-interlaced or progressive sources as shot by 50Hz-frame rate cameras (see section 2.2). It may require the use of an high-cost temporal interpolator at the receiver side or further information coming from an assistance channel.

9 Conclusions

As discussed in this deliverable, both interlaced and progressive formats have their respective advantages and drawbacks. Choosing one of them as the definitive solution of the scanning problem would be utopian, at least when considering today's state of the technology. Nevertheless, it must be stated that one day, technological progress will definitively tip the balance and make it worthwhile to move to a progressive scanning.

Other things being equal, it would objectively represent a poor technical return on investment to move from the interlaced to the progressive scanning : the improved picture quality and the enhanced picture processing do not balance all efforts and costs needed to change the overall television topology in case of adopting a progressive format.

However, the advent of the future digital television will inevitably bring deep changes in this topology : consumers will have to change their television sets (or at least, purchase a digital decoder), broadcasters and studios to adapt themselves to this new technology. In such a context, drastic changes will occur in our current television system. These changes may be seen as a unique opportunity to adopt a progressive scheme, implying only minor costs compared to the overall budget involved in such operation. With the advent of digital television, the question about the uselessness of interlaced scanning will raise since digital coding offers many other ways to save bandwidth. From this analysis it seems that, mostly to achieve an important package of services which will come together with future television, a format conversion toward progressive is desirable. Also, the adoption of a progressive format while changing the television system would be a provident attitude for facing the new requirements which can arise in the future (e.g. multimedia and compatibility with the computer world).

For all these reasons, several progressive formats have already been choosen for the introduction of the new digital HD television in the U.S. [36]. In Japan, the launching a new standard called EDTV-II (*Enhanced Digital TeleVision*) will also make use of a progressive format (480x720, 59.94 Hz) [37]. In a European context, the adoption of a progressive scanning format will have to cope with the decision of the DVB group, which expressed itself in favour of the MP@ML MPEG2 coding scheme. Just as it is, MP@ML does not allow the coding of 50Hz-progressive sequences. However, this limitation only comes from the definition of the MP@ML itself which was decided to restrict the *pixel* rate below the one needed by a 50Hz-progressive format. On a practical/technical point of view, this problem is meaningless since the 50Hz-progressive format may be coded using the same *bit* rate as interlaced at same or improved visual quality. In other words, it would have been more judicious defining the MP@ML to include the 50Hz-progressive format. On the contrary, the 50Hz-progressive format has been classified with other high-cost formats that require a more complex high-1440 level-compliant decoder (MP@H-14). As proposed by the RACE Image Communication Project Line, this syntax problem may be solved by defining an intermediate MPEG2 level compatible with the 50Hz-progressive format.

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PROGRESSIVE AND INTERLACED FORMATS:

COMPARISON AND CODING EFFICIENCY

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ABSTRACT

Progressive format provides higher quality picture, avoiding the artefacts typical of interlaced signals and facilitates the picture processing and the multilevel coding approach. On the other hand, progressive scanned pictures present twice the number of samples of the interlaced ones, but their vertical and temporal correlations are higher if the progressive pictures have the same vertical resolution of the interlaced pictures.

The paper compares the coding efficiency between interlaced and progressive pictures, and reports the results of computer simulations performed at different bit-rates, using a hybrid DCT coding scheme. The progressive and interlaced signals have been suitably processed in order to produce the same vertical resolution for the static pictures. The results indicate that the coding efficiency is higher for the progressive pictures than for the interlaced ones. Based on preliminary results, the paper indicates that also de-interlaced sequences can present coding efficiency higher than interlaced pictures. If confirmed by further results, it is possible, in an interim period, to produce and process interlaced TV signals in the video studios and then to convert them to encode and broadcast progressive TV signals.

The paper does not consider the influence of noise, added to the pictures by the TV camera, on the coding efficiency. In fact, the SNR ratio of the TV camera is a function of its bandwidth, and the progressive camera has twice the bandwidth of the interlaced one.

1 INTRODUCTION

In the past, when the analogue television was designed, the choice of an interlaced scanning format has been very effective. In fact, the temporal and static vertical resolutions were the same of a progressive scanned video signal, but the involved bandwidth was halved. The artefacts of the interlaced format, i.e. line-twitter and line-crawling, were masked by the technology of the displays and cameras. Thus, an interlaced format provided about the same picture quality of a progressive format, but required cheaper video equipment, i.e. TV camera, display, mixer, recorders, etc., and narrower transmission channels.

Today, the higher technology level of the displays highlights the artefacts of the interlaced formats, hence a progressive format will avoid such artefacts improving the picture quality. Its adoption will facilitate the picture processing as filtering, down and up-conversion, standard conversion, motion estimation, and slow-motion. It could be particularly beneficial for the receiver because it would simplify spatial and temporal up-conversions, providing a higher quality of the converted pictures, and would favour the interoperability with the world of computers. Multilevel approaches considered for terrestrial and satellite broadcasting, to provide the viewer with different levels of resolution, are facilitated and improved using progressive formats.

Moreover, the digital encoding and transmission of the video signal are not related to the signal bandwidth, but to the bit-rate of the coded signal. Hence, the coding efficiency of progressive and interlaced scanned video signal must be considered.

2. SOURCE SIGNAL

2.1 Progressive and interlaced formats

Progressive scanning is the most direct approach to represent a two-dimensional images and is normally used in computer applications. CCIR Rec. 709 indicates some parameters for the HDTV signal and points out that the objective for the system is defined to be progressive scanning format

In the digital domain, interlacing or line-quincunx subsampling introduces a reduction factor of two on the sampling rate. The interlacing maintains the vertical resolution in static pictures, but introduces the above mentioned artefacts. The line-quincunx causes a reduction of the diagonal resolution, generally less perceptible, on static and moving pictures.

Similar reduction factor of the final information can be achieved by applying digital compression techniques to the progressive pictures, exploiting the spatial redundancy. A better overall performance can be expected. For example, in the case of video recording a progressive format could provide better performance in slow motion and still picture at expenses of an increased complexity; in studio and at the user's home, high quality standard conversions and spatial and temporal up-conversions could be provided with lower complexity.

A severe limitation in the performance of tube and CCD cameras is the greater drawback in adopting the progressive formats. In fact a reduction of 9 dB of the S/N ratio occurs in the case of tube cameras, and 6 dB loss in sensitivity occurs in the case of CCD cameras. This penalty is principally important for the HDTV camera whose performance in terms of S/N ratio, for the tube cameras, and sensitivity, for the CCD cameras, are presently not so high as conventional TV cameras [1]. The increased noise on progressive pictures could reduce the performance of an HDTV coding system, but, likely, does not affect perceptibly the performance of a TV coding system.

2.2 Considerations on the camera response

The electric charge on the target of a tube camera is a function of light intensity and of the exposition time. On the other hand, the exposition time limits the temporal resolution of the camera, hence it must be limited [2].

The scanning beam interrogates the target, and, in order to provide a high temporal resolution, discharges the entire target at each field. To this end, the scanning beam must cover all the surface of the target with overlapping. The vertical extension of the scanning beam must be at least equal to the distance between two lines scanned in the same field and limits the vertical resolution of the camera. Ideally, ignoring the beam modification effects such as beam self-sharpening, the beam spot can be considered circular with a Gaussian profile of the beam current density. Its modulation transfer function, MTF, will be a symmetrical Gaussian curve in both the vertical and horizontal directions [1].

The distance between lines of each field in an HDTV camera is half that of a conventional TV camera, then the vertical beam spot aperture can be halved maintaining the same temporal resolution of the TV camera. A progressive TV camera has the same number of line per frame of an interlaced TV camera, but a double number of lines per field. Therefore, the distance between lines in the field is half that of a TV interlaced camera and the beam spot can be made finer, increasing the vertical resolution. The spatial and frequency characteristics for the HDTV interlaced camera (HDTV-I), and the conventional definition TV interlaced (CDTV-I) and progressive (CDTV-P) cameras are depicted in Figure 1. The trade-off between increased vertical resolution and vertical aliasing must be accurately considered and optimised, mainly in the case of the progressive camera.

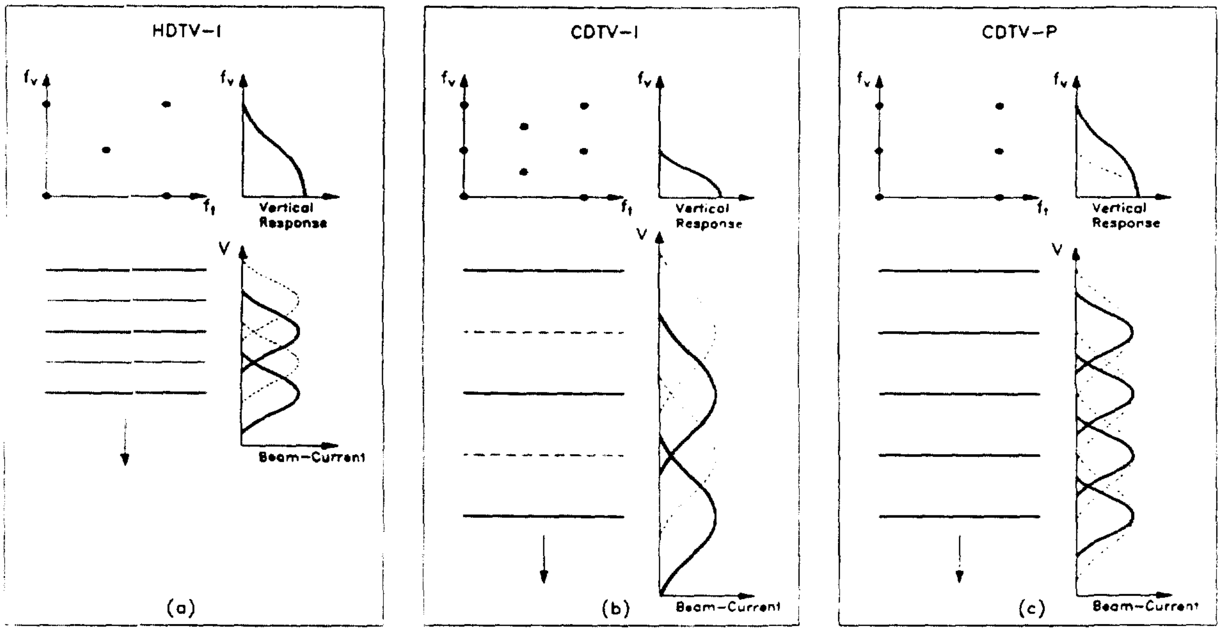

Fig. 1 - Camera response

2.3 Implications for the studios and the receivers

The progressive scanning formats have the mentioned merits of processability and interoperability with the computer graphics and film production and the demerit of a lower S/N ratio caused by the TV camera. Further drawbacks are the implications of progressive formats in the video studio environment. In fact, all the studio equipment presently developed is based on interlaced formats, therefore the implications in terms of standardisation efforts and investments to design and develop equipment suitable to operate with progressive signals are not negligible.

On the other hand, it is likely that significant investments are necessary also to modify the present TV studios, equipped for the present composite signals (PAL, NTSC, SECAM) to operate in digital component TV and HDTV.

The progressive TV and HDTV signals have a sample rate double of the interlaced ones. The cost of a digital video studio is related also to the sample rate of the TV signal; hence, the cost of a progressive TV studio might be higher than the cost of an interlaced TV studio. However, studies and tests carried out at the RAI - Research Centre showed that the enhancement of resolution inherent to the interlaced HDTV with respect to the interlaced TV defined by CCIR Rec. 601 (EDTV), is hardly appreciated with screen size lower than 45" [3]. Informal evaluations indicate that a progressive EDTV further reduces the subjective advantage of an interlaced HDTV. Therefore, progressive EDTV could represent an appealing choice in the near future to promote a high quality digital video service and to limit the investments required for video studios; a progressive EDTV studio likely requires less investments than an interlaced HDTV studio. The progressive HDTV format, indicated in CCIR Rec. 709, could be the natural and compatible choice, in the longer term.

Different classes of receiver and displays can be envisaged, if a high quality progressive signal is available. The receiver could display the progressive signal exploiting its quality features or it could obtain an interlaced signal simply omitting one video line each two and display it on a cheaper display.

3. PROGRESSIVE VS. INTERLACED COMPARISON

3.1 Coding scheme

Hybrid DCT algorithm without rate control, and with Intra-field, motion compensated inter-field and motion compensated inter-frame, coding modes was adopted on interlaced pictures; intra-frame and motion compensated inter-frame coding modes was used on progressive pictures. The motion vectors are evaluated using a block-matching technique with half pel and half line accuracy.

The DCT coefficients have been quantised using a quasi-linear quantiser and the bit-rate has been considered equal to the entropy of the DCT quantised coefficients. This considers an ideal VLC; the implemented VLC's have a coding efficiency, indicated as entropy/bit-rate ratio, lower than, but quite closed to 1. Coding distortion has been measured by non-weighted Spp/Nrms ratio expressed in dB, where Nrms indicates the root mean square value of the differences between the decoded pictures and the original ones and Spp is equal to the nominal signal range. The coding noise bandwidth is equal to the signal bandwidth, hence, it is twice for the progressive signal compared to the interlaced signal. Entropy and coding distortion refer only to the luminance component of the picture.

When specified, the weighting matrix defined by CCIR Rec. 723 was used on interlaced pictures; a similar weighting, modified taking into account the doubling of the vertical frequency, was adopted on progressive pictures.

3.2 Test sequences

Three progressive sequences have been considered: "Renata", shot at the RAI-Research Centre, "Street Dance", and "Flags Waving" kindly provided by NTL-UK. The pictures were shot by a camera designed for interlaced HDTV pictures (1250/50/2:1). Such a camera can also operate without interlacing and shoots progressive TV pictures (625/50/1:1).

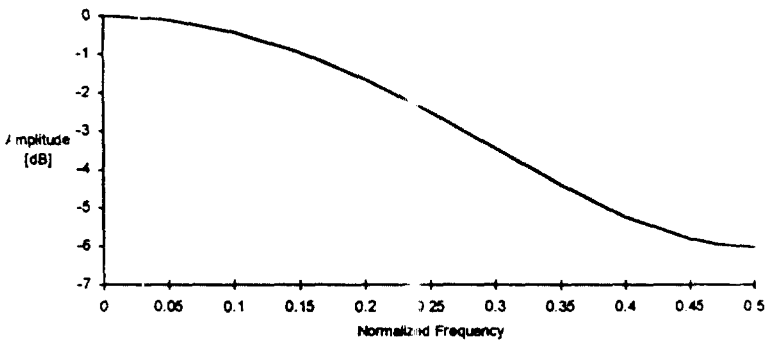

Fig. 2 - Frequency characteristics of a vertical digital 3 taps FIR filter whose coefficients are: 0.125, 0.75, 0.125.

The MTF characteristics of the used camera provide a vertical resolution higher than that available with a TV interlaced camera, as indicated in Figure 1. Hence, the interlaced pictures were obtained from the progressive ones operating a vertical sub-sampling preceded by a vertical FIR filter approaching the MTF of a DTV interlaced camera, see Figure 2. The same filter has also been used to produce progressive sequences with a vertical resolution equal to the vertical static resolution of the interlaced pictures.

3.3 Trade-off between resolution and entropy

Figure 3 reports the characteristics Spp/Nrms ratio versus entropy of the luminance component of progressive and vertically filtered progressive sequences. The sequences have been coded using the hybrid-DCT coding scheme without weighting matrix. The filtering process produces a high increase of the coding efficiency, strong reduction of the entropy at the same coding distortion level, but decreases the vertical resolution of the picture. The bit-rate required by the vertically filtered progressive pictures, ranges from 50% to about 70%, depending on the picture. The ratio between the required bit-rates seems almost independent of the bit-rate value.

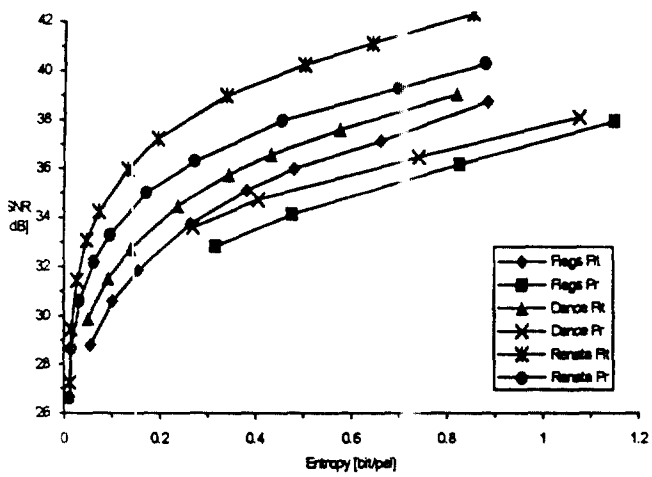

Fig. 3 - SNR [db] versus entropy [bit/pel]. Coding efficiency comparison between progressive and vertically filtered progressive sequences; only luminance samples are considered.

The bit-rate can be also reduced decreasing the number of samples of the picture, i.e. coding interlaced sequences. Such sequences would present the same vertical resolution of the vertically filtered progressive pictures, but the interlaced format provides lower picture quality and requires higher filter complexity for up and down-conversion, as illustrated in the previous items. Moreover, multiresolution systems as subband and pyramidal coding schemes present advantages in terms of complexity and quality at all the resolution levels if the progressive domain instead of the interlaced domain is adopted.

3.4 RESULTS

3.4.1 Intra-field Coding

The coding efficiency of a pure intra-field system coding interlaced or vertically filtered progressive sequences is discussed. Only the luminance component has been reported. The progressive filtered sequences present a higher vertical and temporal correlation, but a pure intra-field system exploits only the vertical one [4].

The curves of signal/coding distortion ratio versus entropy are reported in Figure 4 for the sequences "Flags Waving" and "Renata", respectively. They refer to the coding of interlaced and vertically filtered progressive pictures. The progressive picture entropy has been reported in the figures multiplied by two to take into account the double number of samples. The signal/coding noise ratio is computed evaluating the coding noise in the signal bandwidth.

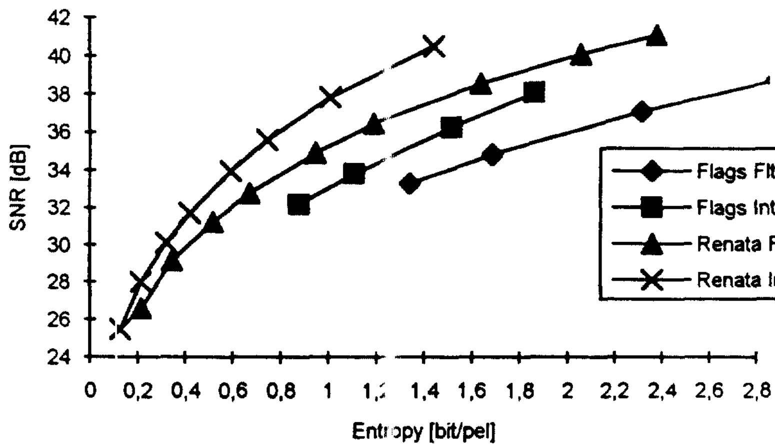

Fig. 4 - SNR [db] versus entropy [bit/pel].
Coding efficiency comparison between vertically filtered progressive and interlaced sequences; only luminance samples are considered. Only Intra-mode is used, without visibility weighting matrix. The entropy values of the progressive sequences are multiplied by two.

Figure 4 indicates that, using a pure intra-field coding system which doesn't exploit the temporal correlation, the vertically filtered progressive pictures require more bit-rate than the interlaced pictures. The progressive/interlace bit-rate ratio varies from about 1.5 at high bit-rate (more than 1 bit/pel for the interlaced picture) to about 1.3 (less than 0.5 bit/pel for the interlaced picture).

3.4.2 Hybrid Coding

The curves of signal/coding distortion ratio versus entropy are reported in Figure 5 without weighting matrix [4] and in Figure 6 with weighting matrix. The curves refer to the coding of interlaced and vertically filtered progressive pictures. As mentioned above, the entropy of the progressive picture has been reported in the figures multiplied by two to take into account the double number of samples of the progressive format. The signal to coding noise ratio is computed evaluating the coding noise in the picture bandwidth.

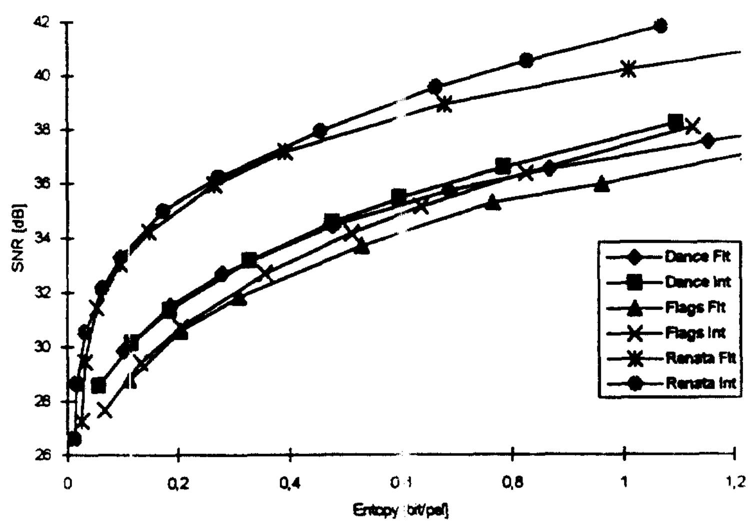

Fig. 5 - SNR [db] versus entropy [bit/pel]. Coding efficiency comparison between vertically filtered progressive and interlaced sequences; only luminance samples are considered. Hybrid-DCT coding scheme, without visibility weighting matrix. The entropy values of progressive sequences are multiplied by two.

Without weighting matrix, Figures 5 indicate that the bit-rate required by the vertically filtered progressive pictures is about equal to that necessary for the interlaced picture when the low bit-rate, less than 0.6 to 0.4 bit/pel, is adopted for the luminance component, depending on the picture. At higher bit-rates, the vertically filtered progressive pictures require more bit-rate than the interlaced pictures, about 1.2 to 1.3 times at 1 bit/pel for the luminance component.

The adoption of the weighting matrix does not modify the results indicated above, see Figure 6.

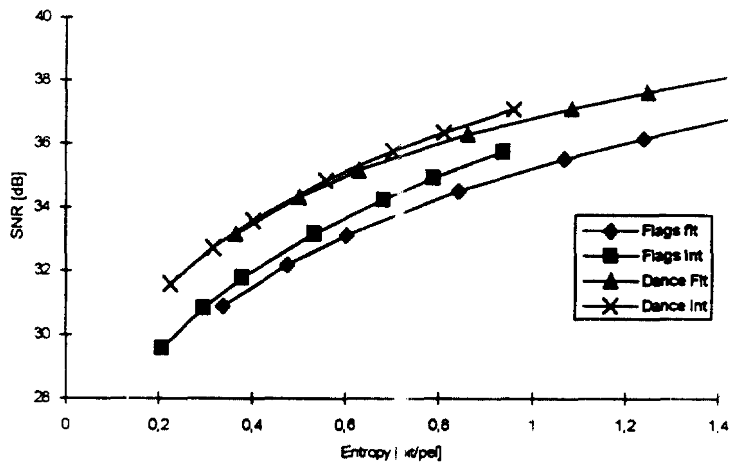

Fig. 6 - SNR [db] versus entropy [bit/pel]. Coding efficiency comparison between vertically filtered progressive and interlaced sequences; only luminance samples are considered. Hybrid-DCT coding scheme, with visibility weighting matrix. The entropy values of progressive sequences are multiplied by two.

3.4.3 *Result analysis*

Progressive pictures have higher vertical and temporal correlation than the interlaced pictures, but present twice the number of samples of the interlaced ones. Exploiting only the increased vertical correlation, intra-field DCT, it is not possible to compensate completely the increased number of samples, so the progressive picture will require more bit-rate than the interlaced ones.

On the contrary, a whole compensation is obtained if the increased temporal correlation is also exploited, hybrid DCT. At low bit-rates, the progressive and interlaced pictures require about the same bit-rate. At high bit-rates, greater than 1 bit/pel for the interlaced picture, the progressive picture requires about 20% or 30% more bit-rate than the interlaced one.

The signal to noise ratio has been evaluated computing the coding noise on the picture bandwidth which is double for the progressive picture. Hence, if the interlaced coded picture is displayed on a progressive display via up-conversion, the coding noise of the up-converted picture is concentrated on the low frequencies and then subjectively more visible than the one of the progressive coded picture with the same coding noise. The down and up-conversion of the progressive coded signal at the receiver side will have the same resolution of the coded interlaced picture, but a gain of 3 dB in SNR. Moreover, if the progressive coded picture is displayed on an interlaced display, a pre-filter can reduce the noise with a gain of 3dB in SNR.

On the other hand, progressive scanning camera and interlaced scanning camera have different noise characteristics. Usually, progressive scanning sequences have less S/N ratio than the interlaced sequences and this could reduce the performance of the coding system, mainly in the case of HDTV pictures.

4. DE-INTERLACED VS. INTERLACED COMPARISON

Preliminary results indicate that de-interlaced pictures can present higher coding efficiency than interlaced pictures, as the progressive ones, if an improved coding scheme